A Petroleum R&D Project Portfolio Investment Selection Model with Project Interactions under Uncertainty

Danmei Zhu[1], Xingtong Wang[2]

[1] School of Science, Liaoning Shihua University, Fushun, 113001, China
[2] Fushun Research Institute of Petroleum and Petrochemicals, SINOPEC, Fushun, 113001, China
[1] zhudanmei@126.com; [2] waxito3ng@163.com

Abstract- **At present, most of petroleum R&D project portfolio researches are based on mathematical programming, decision theory and scoring method to construct R&D project portfolio multi-criteria model. These models is effective to some extent, however, it is very rare to consider the uncertainty of project and petroleum R&D project interactions in R&D portfolio selection. In this paper, firstly, fuzzy set theory and real option method have been combined in petroleum R&D project portfolio decision analysis, and we have also considered project interactions in order to seek the optimal solution. Finally, an example of petroleum R&D project portfolio carried out systematic evaluation and empirical analysis.**

Keywords-* *Petroleum Projects Portfolio; Fuzzy Set; Real Option; Project Interactions

I. INTRODUCTION

Nowadays, rapid technological developments, organizational changes and increased demand for efficiency in the petroleum industry have all brought risk variability to petroleum project investment. When the future outcomes of a firm’s endeavors are unknown, a key strategy for dealing with such risk is betting on more than one horse. Successful research and development (R&D) policy therefore requires careful portfolio analysis to optimize the selection and the development of several concurrent alternatives. At present, the studies on R&D projects portfolio are mostly concentrated in the multi-criteria model; these models include mathematical programming models, decision theory models and scoring models [1-3]. However, there are still two problems. First, these selection models obtain optimal solutions by exact mathematical relationships between the objectives and constraints in model. But the R&D project portfolio decision deals with future events and opportunities, much of the information required making portfolio decisions is at best uncertain and at worst very unreliable. Second, the problem of project interactions has long been recognized but has received relatively little attention in the R&D project selection literatures [4-6].

Based on the above analysis, fuzzy set theory was used in this paper to deal with related uncertain information, reflecting the value coming from flexibility of project management decision-making through appending the item of real options of projects to the objective function. At the same time, the objective functions and constraints of the project interactions model will be analyzed based on the relations of benefit, technology and resource, to get the model of fuzzy 0-1 integer programming. Finally, qualitative possibility principle [7] was used to convert the model of fuzzy 0-1 integer programming model to the model of clear 0-1 integer programming, and with the software MATLAB and EXCEL to obtain the optimization solution. There are three main parts of this model: objective function construction, Constraint analysis, model solution.

II. A PETROLEUM R&D PROJECTS PORTFOLIO INVESTMENT SELECTION MODEL

The computational complexity of project portfolio selection problem is closely related to the number of initial projects. Therefore, before the decision is made, project screening is necessary. This procedure consists of two steps: firstly, project strategic consistency assessment. That is, those projects will be retained that can meet the strategic goals of the enterprise. More detailed discussion on project strategic consistency can be found in reference [8].Secondly, project portfolio constraints screening. Those projects will be eliminated from the project set if project cost, resource or other constraint is violated. After two screening process, we can get an initial project set as a preparation for further decision-making.

A. *Objective Function Construction*

1) *Petroleum R&D Project Option Character Analysis*

Assuming there are three stages in petroleum R&D project. Let $\tilde{C}_i$ $(i=1,2,3)$ be the investment cost at the beginning of the three stages, $\tilde{S}$ is the cash inflow after the market popularization, where $\tilde{C}_i$ and $\tilde{S}$ are both estimated by experts with the method of trapezoidal fuzzy numbers. After initial investment, there is a call option. The time limitation is T_1 , and the investment cost $\tilde{C}_2$ in the technology development stage is the exercise price of the first call option. If the first option can be exercised at the time T_1, investment in the stage of technology research can be started. The opportunity for market promotion will be achieved at the time T_2. So the second call option is coming into being. Its exercise price is the cost of market promotion $\tilde{C}_3$. For there are two options and the first causes the emergence of the second, and it’s a compound option. Only under the condition that the value of the second option is higher than the exercise price of the first option, the compound option can be performed at the due date of the first option. The figure of

stages of schematic for R&D projects is shown as follows (Fig. 1).

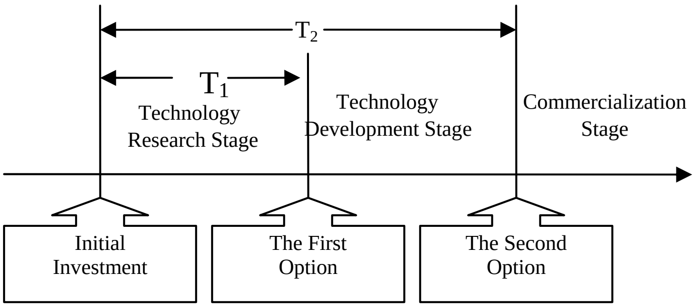

Fig. 1 Stages of schematic for R&D projects

After the above analysis, it's obvious that R&D project investment is a typical compound real option. Investment decision-making of each stage depends on the actual results of investment exercised before. The value of R&D project depends on not only the cash inflow from investment in the stage of technology development but also the value of the opportunities in the later stage of research benefit from the initial investment. If the situation is not as optimistic as expected after the initial investment of research, decision of cutting off later investment should be made immediately to avoid more losses. So by the fuzzy real option model of Carlsson and Fullér [9] and the compound option model of Geske [10], we can establish the fuzzy compound real option evaluation model of R&D project.

$$\tilde{V} = \tilde{S}e^{-\delta T_2}M(a_1, b_1; \sqrt{T_1/T_2}) - \tilde{C}_3 e^{-rT_2}M(a_2, b_2; \sqrt{T_1/T_2}) - \tilde{C}_2 e^{-rT_1}N(a_2) \quad (1)$$

Where, $$a_1 = \frac{\ln[E(\tilde{S})/S^C] + (r - \delta + \sigma^2/2)T_1}{\sigma\sqrt{T_1}}, \quad (2)$$

$$a_2 = a_1 - \sigma\sqrt{T_1}, \quad (3)$$

$$b_1 = \frac{\ln[E(\tilde{S})/E(\tilde{C}_3)] + (r - \delta + \sigma^2/2)T_2}{\sigma\sqrt{T_2}}, \quad (4)$$

$$b_2 = b_1 - \sigma\sqrt{T_2}, \quad (5)$$

and $M(a,b,\rho)$ is the bivariate cumulative standard normal distribution function, with integral upper limit a, integral lower limit b, and correlation coefficient ρ ($\rho = \sqrt{T_1/T_2}$).

$N(\cdot)$ is the single variable cumulative standard normal distribution function;

σ is the volatility of the R&D project benefit;

r is the risk-free interest rate;

S^C is the value of assets when compound option should be exercised. It can be calculated in the equation below:

$$\tilde{S}e^{-\delta(T_2 - T_1)}N(c_1) - E(\tilde{C}_3)e^{-r(T_2 - T_1)}N(c_2) - E(\tilde{C}_2) = 0, \quad (6)$$

Where,

$$c_1 = \frac{\ln[S^C/E(\tilde{C}_3)] + (r - \delta + \sigma^2/2)(T_2 - T_1)}{\sigma\sqrt{T_2 - T_1}}, \quad (7)$$

$$c_2 = c_1 - \sigma\sqrt{T_2 - T_1}. \quad (8)$$

Here, the volatility and dividend of project can be calculated with $\sigma = \sqrt{Var(\tilde{S})}/E(\tilde{S})$ and $\delta = E(\tilde{C}_1)/E(\tilde{S})$ [11]. At the same time, in order to simplify the calculation, the investment cost $\tilde{C}_1$, $\tilde{C}_2$ and the project benefit $\tilde{S}$ defined in the function (2)-(8), can be substituted by their possible mean.

2) R&D Projects Interactions Analysis

The qualitative analysis of interactions of benefit, technology and resource will be performed respectively.

(a) Benefit interaction affect the overall payoff obtained from a portfolio. When benefit interactions are present, the total value of a portfolio is greater or less than the sum of the individual project values. There are two types of benefit interaction: synergism effect and substitution effect. The synergism effect is that the overall benefit of project portfolio exceeds the sum benefit of each individual project. The substitution effect is that a new product project replaces the earlier product project, e.g. the improvement or upgrading of earlier product. At this time the overall benefit of project portfolio will perhaps be inferior to the sum benefit of each individual project.

(b) Technology interactions include two cases, technology interdependence and technology exclusion. Technology interdependence refers to the technology of two projects interrelated to some degree and the implementation of one project is the prerequisite of the other. Assuming there are n projects for selecting, decision-making variables x_i $(i = 1, 2, \cdots, n)$ are defined as follows:

$$x_i = \begin{cases} 1, & \text{the i-th project is in the project portfolio;} \\ 0, & \text{other wise.} \end{cases}$$

If the implementation of project p is the prerequisite of that for project j, then constraints can be expressed as $x_p - x_j \geq 0$. If the two projects are of the type of technology mutually exclusion, only one of them can be implemented, so the constraint is $x_q + x_h \leq 1$.

(c) Resource interactions occur when the total cost of a portfolio is different from the sum of the individual costs. For example, resource interactions arise when equipment or other resources are shared among some projects so that the cost of selecting projects is less than the sum of the individual costs.

Base on the analysis above, we can construct the objective function of optimization model as the sum of real options and the net present value of R&D project portfolio, with consideration of the interactions among projects, to seek for the optimal combination through the analysis of net present value of strategic extension. So the objective function of optimization model is:

$$\max \sum_{i=1}^{n}\left(\tilde{V}_i + \tilde{N}_i\right)x_i + \sum_{j=1}^{u}\Delta\tilde{S}_j y_j - \sum_{k=1}^{v}\Delta\tilde{C}_k z_k \quad (9)$$

The first summation is the sum of real option and net present value of project portfolio; the second and third summation consider respectively the changed quantum of objective function when there exists benefit interactions or resource cost interactions among projects.

In the first part of the objective function, $\tilde{V}_i$ is the value of real option of each project, calculated according to the formula (1). While $\tilde{N}_i$ is the fuzzy set present value of each project, and it can be calculated with the formula as follows:

$$\tilde{N}_i = \frac{\tilde{S}_i}{(1+r)^{iT_2}} - \frac{\tilde{C}_{i3}}{(1+r)^{iT_2}} - \frac{\tilde{C}_{i2}}{(1+r)^{iT_1}} - \tilde{C}_{i1}, \quad i = 1, 2, \cdots, n. \tag{10}$$

The u in the second item of the objective function denotes that there are u kinds of benefit interactions in the n projects to be selected. The *j-th* interaction is composed of m_j *projects. The variable* y_j indicates whether the j-th benefit interaction occurs or not. Here

$$y_j = \prod_{r=1}^{m_j} x_{r,j}, \quad y_j \in \{0,1\} \tag{11}$$

Then y_j is the product of 0-1 variables of the m_j projects between which exists the j-th benefit interaction. It indicates that the j-th benefit interaction will occur only when the m_j projects were totally selected into the project portfolio. $\Delta\tilde{S}_j$ is the change brought by the present value of cash inflow income when the j-th benefit interaction occurs. The value can be positive or negative; and the positive value indicates synergism effect obtained from the j-th benefit interaction while negative indicates substitution effect.

Similarly, the v in the third item of the objective function denotes that there are v types of resource cost interactions in the n projects to be selected. The k-th type of interaction is composed of λ_k projects, the variable z_k shows whether the k-th resource cost interaction occurs or not. Here

$$z_k = \prod_{l=1}^{\lambda_k} x_{l,k}, \quad z_k \in \{0,1\} \tag{12}$$

Then z_k is the product of 0-1 variables of the λ_k projects among which exists the k-th resource cost interaction. It denotes that the k-th resource cost interaction will occur only when the λ_k projects is completely selected into the project portfolio. $\Delta\tilde{C}_k$ is the decrease of the cost present value of cost brought to the project portfolio when the k-th resource cost interaction occurs. Its value is positive.

B. Constraint Analysis of Optimization Model

There are various kinds of constraints of portfolio selection, such as the cost or project interactions and so on. The total funds devoted into the R&D project portfolio are limited. Due to the generally long cycle of a R&D project, corporations will alter their investment cost in the R&D project according to their own property situation and the change of competitive environment. Therefore, the total cost, denoted by trapezoidal fuzzy numbers as $\tilde{C}$, is not an accurate value. Let $\tilde{c}_i$ be the cost of i-th project, cost constraint is $\sum_{i=1}^{n} \tilde{c}_i x_i \le \tilde{C}$. Considering the interactions of resource utilization and cost among projects, therefore

$$\sum_{i=1}^{n} \tilde{c}_i x_i - \sum_{k=1}^{v} \Delta\tilde{C}_k z_k \le \tilde{C} \tag{13}$$

The technology interrelation may exist among R&D projects in the project portfolio, and the analysis is as follows. If two projects are technology interdependent, the implementation of the p-th project is the prerequisite of the implementation of the j-th project, let $P_r \subset \{1, 2, \cdots, n\}$ be the numbered set of this type of projects. So the constraint is:

$$x_p - x_j \ge 0, \quad p, j \in P_r \tag{14}$$

If two projects are technology antagonism, then only one project of the q-th and h-th can be implemented. Let $P_o \subset \{1, 2, \cdots, n\}$ be the numbered set of these projects, the constraint is:

$$x_q + x_h \le 1, \quad q, h \in P_o . \tag{15}$$

Some projects must be implemented by the corporation, and projects that are in-process can also be put in this type. Let $P_m \subset \{1, 2, \cdots, n\}$ be the numbered set of these projects, and the constraint is:

$$x_m = 1, \quad m \in P_m \tag{16}$$

To analyze formulae (9)-(16), we can obtain the fuzzy 0-1 integer programming model of R&D project portfolio selection. Among them, the formula (9) is the objective function, others are constraint functions.

III. MODEL SOLUTION

For the fuzzy 0-1 integer programming model above, we can use the qualitative possibility theory to translate it into a clear 0-1 integer programming model.

With the example of formula (13), we are going to explain how to translate the fuzzy constraint function into the generally resolvable integer programming constraint function with the qualitative possibility theory. If decision-maker considers that the satisfaction degree of the constraint function (13) is higher than λ , we can get Inequality (17) as

$$C\left(\sum_{i=1}^{n} \tilde{c}_i x_i - \sum_{k=1}^{v} \Delta\tilde{C}_k z_k, \tilde{C}\right) \ge \lambda \tag{17}$$

Further,

$$\sum_{i=1}^{n} c_i^{c_r} x_i - \sum_{k=1}^{v} \Delta C_k^{c_l} z_k + \lambda\left(\sum_{i=1}^{n} x_i c_i^{r} + \sum_{k=1}^{v} \Delta C_k^{r} z_k\right) \le C^{c_r} + (1-\lambda)C^{r} \tag{18}$$

Where $c_i^{c_r}, \Delta C_k^{c_l}$ are respectively the right boundary value and the left boundary value of $\tilde{c}_i, \Delta\tilde{C}_k$, with the membership degree as 1. Take the trapezoidal fuzzy number $\tilde{C} = (C^l, C^{c_l}, C^{c_r}, C^r)$ as an example, a detailed explanation can seen from Figure 2.

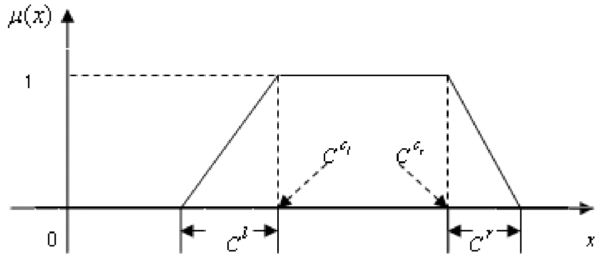

Fig. 2 Graphical interpretation of the trapezoidal fuzzy number $\tilde{C}$

Similarly, for the objective function, if the decision-maker considers that the satisfaction degree of the objective function is higher than γ , then the objective function can be transformed into

$$Max \;\; z$$

$$s.t. \quad C\left(\sum_{i=1}^{n}\left(\tilde{V}_i+\tilde{N}_i\right)x_i+\sum_{j=1}^{u}\Delta\tilde{S}_j y_j-\sum_{k=1}^{v}\Delta\tilde{C}_k z_k,\;\; z\right)\ge\gamma \tag{19}$$

Namely

$$Max \quad \sum_{i=1}^{n}\left(V_i^{c_l}+N_i^{c_l}\right)x_i+\sum_{j=1}^{u}\Delta S_j^{c_l}y_j-\sum_{k=1}^{v}\Delta C_k^{c_r}z_k$$
$$-\gamma\left(\sum_{i=1}^{n}\left(V_i^{l}+N_i^{l}\right)x_i+\sum_{j=1}^{u}\Delta S_j^{l}y_j+\sum_{k=1}^{v}\Delta C_k^{l}z_k\right) \tag{20}$$

Where

$$\begin{aligned}\tilde{V}_i&=(V_i^{c_l},V_i^{c_r},V_i^{l},V_i^{r}),\\ \tilde{N}_i&=(N_i^{c_l},N_i^{c_r},N_i^{l},N_i^{r}),\\ \Delta\tilde{S}_j&=(\Delta S_i^{c_l},\Delta S_i^{c_r},\Delta S_i^{l},\Delta S_i^{r}),\\ \Delta\tilde{C}_k&=(\Delta C_i^{c_l},\Delta C_i^{c_r},\Delta C_i^{l},\Delta C_i^{r})\end{aligned} \tag{21}$$

It is clear that their definitions are similar to $\tilde{C}$.

Through the above transformation, the formulae (9) - (16) were turned into clear 0-1 integer programming problem as following:

$$Max \quad \sum_{i=1}^{n}\left(V_i^{c_l}+N_i^{c_l}\right)x_i+\sum_{j=1}^{u}\Delta S_j^{c_l}y_j-\sum_{k=1}^{v}\Delta C_k^{c_r}z_k$$
$$-\gamma\left(\sum_{i=1}^{n}\left(V_i^{l}+N_i^{l}\right)x_i+\sum_{j=1}^{u}\Delta S_j^{l}y_j+\sum_{k=1}^{v}\Delta C_k^{l}z_k\right) \tag{22}$$

$$s.t. \quad \sum_{i=1}^{n}c_i^{c_r}x_i-\sum_{k=1}^{v}\Delta C_k^{c_l}z_k+\lambda\left(\sum_{i=1}^{n}x_ic_i^{r}+\sum_{k=1}^{v}\Delta C_k^{r}z_k\right) \tag{23}$$
$$\le C^{c_r}+(1-\lambda)C^{r}$$

$$x_p-x_j\ge 0,\quad p,j\in P_r \tag{24}$$

$$x_q+x_h\le 1,\quad q,h\in P_o \tag{25}$$

$$x_m=1,\quad m\in P_m \tag{26}$$

$$y_j=\prod_{r=1}^{m_j}x_{r,j},\qquad y_j\in\{0,1\} \tag{27}$$

$$z_k=\prod_{l=1}^{\lambda_k}x_{l,k},\qquad z_k\in\{0,1\} \tag{28}$$

$$x_i,x_{r,j},x_{l,k}\in\{0,1\},P_r,P_o,P_m\subset\{1,2,\cdots,n\},0\le m_j,\lambda_k\le n \tag{29}$$

The above clear 0-1 integer programming model can be solved with the corresponding EXCEL Programming Solver software, thus to get the optimal solution of R&D project portfolio selection.

IV. CASE ANALYSIS AND CONCLUSIONS

In this section, we will verify the rationality of the method in this article by an example of R&D project portfolio selection in petroleum industry. There are fifty projects to be selected, according to the scores from experts; the petroleum corporation can initially screen out twenty R&D projects which are in accordance with the strategy development of the corporation. For these initially selected projects, each one is composed of three stages of production technology research, technology development testing and commercial popularization. For simplicity, we can assume all the due dates of the first and second options included in all the projects are $T_1=3$, $T_2=10$. The expected cost of the project portfolio with three stages expressed with the trapezoidal fuzzy numbers, are respectively (0, 200, 0, 20)、(0, 700, 0, 100)、(0, 1500, 0, 200), with the unit being millions of dollars; analogously, the limitation of human resources capacity of the project portfolio with three stages, are respectively (0, 374.5, 0, 50)、(0, 1964.9, 0, 250)、(0, 1319.5, 0, 160), with the unit being the number of months. Table 1 and Table 2 respectively present the stage investment cost, expected cash inflow and required human resources in each stage for the 20 projects selected initially.

In addition, these twenty projects can be divided into three types of sets, namely: the set of new production S_1, the set of derivatives of existing production S_2 (such as those re-packaged, renamed), the set of Performance improvements of existing production S_3. And the twenty projects belong to the three sets, as follows:

S_1={#13, #14, #16, #17, #18, #19, #20};
S_2={#5, #6, #8, #9, #10, #15};
S_3= {#1, #2, #3, #4, #7, #11, #12}.

At the same time, in order to achieve the strategic balance of project portfolio selection, it is required that the three types S_1, S_2, S_3 account for 40-70%, 20-40%and 10-30% in the project portfolio, respectively. Risk-free interest is 4%.

TABLE I RESOURCE DATA FOR PROJECTS

Project No.	**investment cost of stage (unit : millions of dollars)**			**Expected cash inflow $\tilde{S}$**
	$\tilde{C}_1$	$\tilde{C}_2$	$\tilde{C}_3$	
1	(2,2,0.3,0.3)	(30,30,4.5,4.5)	(30,30,4.5,4.5)	(50,50,5,5)

2	(3,3,0.45,0.45)	(50,50,7.5,7.5)	(45,45,6.75,6.75)	(100,100,10,10)
3	(10,10,1.5,1.5)	(75,75,11.25,11.25)	(100,100,15,15)	(200,200,25,25)
4	(5,5,0.75,0.75)	(65,65,9.75,9.75)	(170,170,25.5,25.5)	(200,200,10,25)
5	(20,20,3,3)	(85,85,12.75,12.75)	(200,200,30,30)	(600,600,50,50)
6	(15,15,2.25,2.25)	(40,40,6,6)	(45,45,6.75,6.75)	(100,100,5.5,5.5)
7	(7,7,1.05,1.05)	(35,35,5.25,5.25)	(30,30,4.5,4.5)	(80,80,4.5,4.5)
8	(5,5,0.75,0.75)	(55,55,8.25,8.25)	(50,50,7.5,7.5)	(100,100,4.35,5)
9	(10,10,1.5,1.5)	(75,75,11.25,11.25)	(80,80,12,12)	(180,180,20,25)
10	(18,18,2.7,2.7)	(85,85,12.75,12.75)	(120,120,18,18)	(380,380,20,25)
11	(5,5,0.75,0.75)	(35,35,5.25,5.25)	(30,30,4.5,4.5)	(80,80,7.5,10)
12	(7,7,1.05,1.05)	(40,40,6,6)	(60,60,9,9)	(100,100,10,15)
13	(15,15,2.25,2.25)	(95,95,14.25,14.25)	(180,180,27,27)	(400,400,40,45)
14	(35,35,5.25,5.25)	(120,120,18,18)	(280,280,42,42)	(700,700,50,55)
15	(25,25,3.75,3.75)	(70,70,10.5,10.5)	(100,100,15,15)	(500,500,10.5,12)
16	(15,15,2.25,2.25)	(95,95,14.25,14.25)	(150,150,22.5,22.5)	(300,300,8.5,8.5)
17	(17,17,2.55,2.55)	(80,80,12,12)	(180,180,27,27)	(350,350,20,22)
18	(20,20,3,3)	(90,90,13.5,13.5)	(220,220,33,33)	(550,550,45,50)
19	(35,35,5.25,5.25)	(120,120,18,18)	(250,250,37.5,37.5)	(800,800,50,55)
20	(50,50,7.5,7.5)	(130,130,19.5,19.5)	(350,350,52.5,52.5)	(450,450,90,85)

TABLE II REQUIRED HUMAN RESOURCES FOR PROJECTS

Project No.	Required human resources (unit: month)		
	technology research stage	**technology development testing stage**	**commercial popularization stage**
1	(2,2,0.3,0.3)	(30,30,4.5,4.5)	(30,30,4.5,4.5)
2	(3,3,0.45,0.45)	(50,50,7.5,7.5)	(45,45,6.75,6.75)
3	(10,10,1.5,1.5)	(75,75,11.25,11.25)	(100,100,15,15)
4	(5,5,0.75,0.75)	(65,65,9.75,9.75)	(170,170,25.5,25.5)
5	(20,20,3,3)	(85,85,12.75,12.75)	(200,200,30,30)
6	(15,15,2.25,2.25)	(40,40,6,6)	(45,45,6.75,6.75)
7	(7,7,1.05,1.05)	(35,35,5.25,5.25)	(30,30,4.5,4.5)
8	(5,5,0.75,0.75)	(55,55,8.25,8.25)	(50,50,7.5,7.5)
9	(10,10,1.5,1.5)	(75,75,11.25,11.25)	(80,80,12,12)
10	(18,18,2.7,2.7)	(85,85,12.75,12.75)	(120,120,18,18)
11	(5,5,0.75,0.75)	(35,35,5.25,5.25)	(30,30,4.5,4.5)
12	(7,7,1.05,1.05)	(40,40,6,6)	(60,60,9,9)
13	(15,15,2.25,2.25)	(95,95,14.25,14.25)	(180,180,27,27)
14	(35,35,5.25,5.25)	(120,120,18,18)	(280,280,42,42)
15	(25,25,3.75,3.75)	(70,70,10.5,10.5)	(100,100,15,15)
16	(15,15,2.25,2.25)	(95,95,14.25,14.25)	(150,150,22.5,22.5)
17	(17,17,2.55,2.55)	(80,80,12,12)	(180,180,27,27)
18	(20,20,3,3)	(90,90,13.5,13.5)	(220,220,33,33)
19	(35,35,5.25,5.25)	(120,120,18,18)	(250,250,37.5,37.5)
20	(50,50,7.5,7.5)	(130,130,19.5,19.5)	(350,350,52.5,52.5)

TABLE III FUZZY OPTION VALUES FOR 20 CANDIDATE PROJECTS

Project No.	Fuzzy option values	Project No.	Fuzzy option values
1	(16.35,16.35,3.65,3.65)	11	(11.32,11.32,4.50,5.30)
2	(36.89,36.89,8.59,8.59)	12	(24.60,24.60,5.45,7.28)
3	(41.85,41.85,16.07,16.07)	13	(97.83,97.83,40.67,43.45)
4	(72.71,72.71,12.65,21.49)	14	(195.18,195.18,48.70,51.22)
5	(270.34,270.34,50.24,50.24)	15	(181.94,181.94,21.96,22.82)
6	(0,0,0,0)	16	(126.59,126.59,9.06,9.06)
7	(7.55,7.55,2.36,2.36)	17	(111.02,111.02,18.94,19.92)
8	(25.42,25.42,4.22,4.49)	18	(176.98,176.98,52.40,55.50)
9	(37.03,37.03,12.48,14.40)	19	(335.18,335.18,47.91,50.80)
10	(102.10,102.10,25.25,27.89)	20	(398.15,398.15,106.74,103.56)

TABLE IV BENEFIT, TECHNOLOGY AND RESOURCE INTERACTIONS AMONG PROJECTS

Type of interactions	projects	effects of interaction
Benefit interactions	2，5	synergism effect $\Delta S1=(50,50,4.5,4.5)$
	11，17	Substitution effect $\Delta S2=(-30,-30,4,4)$
Technology interactions	3，4	the implement of project 3 is the prerequisite of the implement of project 4
	16，17	Projects 16 and 17 are mutually exclusive
	6	Project 6 must be implemented
Resource interactions	2，15	Saving cost $\Delta C=(50,50,5.5,5.5)$

TABLE V PROJECTS PORTFOLIO SELECTION RESULT ($\gamma=0.95$, $\lambda_{1t}=0.1-0.99$, $\lambda_{2t}=0.9,\ t=1,2,3$)

λ_{1i}	selected project			Objective value
	Strategy 1	Strategy 2	Strategy 3	
0.1	16,18,19,20	5,6,10,15	2,11	2022.91
0.2	17,18,19,20	5,6,10,15	1,2	2009.80
0.3	17,18,19,20	5,6,10,15	2	1999.75
0.4	18,19,20	5,6,10,15	1,2,7	1922.72
0.5	16,18,19,20	5,6,15	2	1908.55
0.6	16,18,19,20	5,6,15	2	1908.55
0.7	16,18,19,20	5,6,15	2,11	1714.60
0.8	16,18,19,20	5,6,15	2,11	1714.60
0.9	16,19,20	5,6,15	2,11	1714.60
0.95	16,19,20	5,6,15	1,2	1710.283
0.99	16,19,20	5,6,15	1,2	1710.283

By calculating, when $\gamma=0.95$, $\lambda_{1t}=0.1-0.99\ (t=1,2,3)$, $\lambda_{2t}=0.9\ (t=1,2,3)$, we can get the portfolio selection result considering the interactions among projects, as in Table 5.

First of all, through the calculated results of Table 5, we can see that the project portfolio selection model has indeed considered the interactions among projects. For example, for the benefit interactions among projects, due to the synergism effect between project 2 and project 5, the emergence of both of them at the same time is able to increase the benefit of the project portfolio, which is precisely reflected in the result calculated. On the contrary, due to the substitution effect between project 11 and project 17, the emergence of them at the same time will surely decrease the benefit of the project portfolio; such relation is also precisely reflected in the result calculated. For all kinds of schemes of project selection, project 2 and project 5 will surely be at the same time, while project 11 and project 17 will surely not be at the same time. For the technology interactions among projects, as the implementation of project 3 is the prerequisite of the implementation of project 4, seeing from the calculation results, project 3 and project 4 do not emerge in all the schemes of project selection, we can conclude that this result is also in line with the assumptions of the technology interactions. For the reason that projects 16 and 17 are mutually exclusive projects, in the calculation results, in all kinds of schemes of project selection, project 16 and project 17 never emerges at the same time. The project 6 which must be implemented emerges in all the schemes. Finally, let's look at the resource interactions between projects. Due to the resource interactions between project 2 and project 15, the emergence of both of them at the same time can save the cost of resources, and it can be seen in the calculation result that project 2 and project 15 emerge at the same time in all the schemes, which is in line with the assumptions of the resource interactions between two projects.

Secondly, by analyzing the data, we can also find when the cost constraints satisfaction degrees are different; we can get different project portfolio values (objective function value). Figure 3 shows that the project portfolio values vary with the cost constraints satisfaction degree when other conditions are the same. It can be seen when it is $\lambda_{1i}=0.3$, 0.4, 0.6, 0.7 (i = 1, 2, 3), the portfolio value will vary rapidly, while in other parts, it is relatively smooth. Decision-makers can adjust the cost constraints according to the demonstrated results of the model. Grasping a few key points, it may lead to greater benefit for investment decision-making.

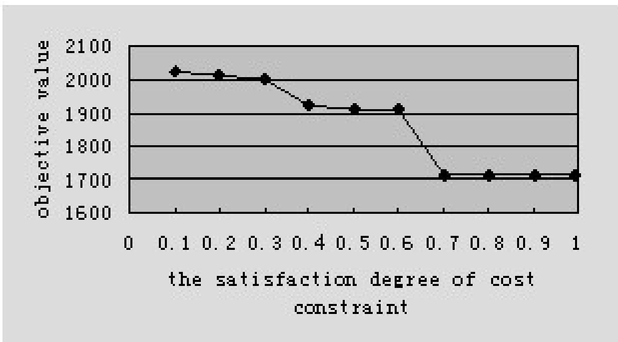

Fig. 3 Project portfolio value for different cost constraints satisfaction degree

Finally, this article is specific to different calculations of the cost constraint satisfaction. Of course, you can also use

different satisfaction degree in objective function or human resources constraints. You will get a different portfolio scheme with different parameter, and we will not repeat them here.

REFERENCES

[1] A. D. Henriksen, A. J. Traynor, "A practical R&D project-selection scoring tool," *IEEE Transactions on Engineering Management*, vol. 46, PP. 158-170, 1999.

[2] G. J. Beaujon, S. P. Marin, G. C. McDonald, "Balancing and optimizing a portfolio of R&D projects," *Naval Research Logistics* , vol.48, PP.18-40, 2001.

[3] J.L. Ringuest, S.B. Graves, R.H. Case, "Mean-Gini analysis in R&D portfolio selection,"*European Journal of Operational Research*, vol.154(1), PP. 157-169, 2004.

[4] C. Carlsson, R. Fullér. "A fuzzy approach to R&D project portfolio selection," *International Journal of Approximate Reasoning,* vol. 44, PP. 93-105, 2007.

[5] C.H. Lin，P.J. Hsieh, "A fuzzy decision support system for strategic portfolio management," *Decision Support Systems*, vol.38, PP. 383-398, 2004.

[6] S. van Bekkum et al. "A real options perspective on R&D portfolio diversification," *Research Policy*, vol.38, PP.1150–1158, 2009.

[7] D. Dubois, H. Prade, "Qualitative possibility theory and its applications to constraint satisfaction and decision under uncertainty," *International Journal of Intelligent Systems*, vol.14, pp.45-61, 1999.

[8] Kun M, "Research on the method of project portfolio selection," M. Eng. thesis , Hefei University of Technology, 2008.

[9] C. Carlsson, R. Fullér, "A fuzzy approach to real option valuation ," *Fuzzy Sets and Systems*, vol. 139, pp. 297-312, 2003.

[10] R. Geske , "The valuation of compound options, " *Journal of Financial Economics*, vol. 7, pp. 63-81, 1979.

[11] G. J. Klir, B. Yuan, *Fuzzy sets and fuzzy logic: theory and applications*, Englewood Cliffs, NJ: Prentice-Hall, 1995.